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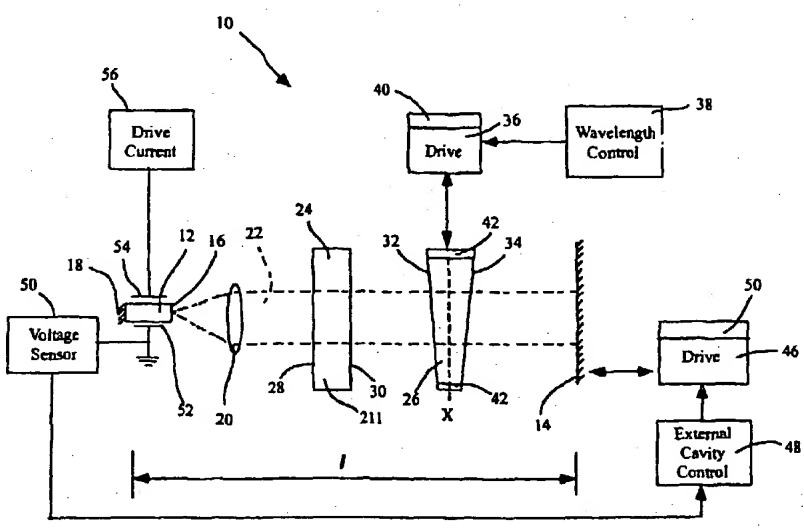
(54) Title: EXTERNAL CAVITY LASER APPARATUS WITH ORTHOGONAL TUNING OF LASER WAVELENGTH AND CAVITY OPTICAL PATH LENGTH



(57) Abstract: An external cavity laser apparatus and method wherein wavelength or channel selection is carried independently from adjustment of external cavity optical path length. The apparatus comprises a wavelength or channel selector tuner and an external cavity tuner, wherein the wavelength tuner is uncoupled from the external cavity tuner. The tuning mechanisms for wavelength selection and cavity optical path length are configured to operate independently or orthogonally with respect to each other. The wavelength tuner may operate according to a first, channel selection signal, while the external cavity tuner operates according to a second, external cavity adjustment signal. The wavelength tuner and external cavity tuner may operate under the control of the same,

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External Cavity Laser Apparatus with Orthogonal Tuning of Laser Wavelength and Cavity Optical Path Length

Background Of The Invention

Fiber optic telecommunications are continually subject to demand for increased bandwidth. One way that bandwidth expansion has been accomplished is through dense wavelength division multiplexing (DWDM) wherein multiple separate data streams exist concurrently in a single optical fiber, with modulation of each data stream occurring on a different channel. Each data stream is modulated onto the output beam of a corresponding semiconductor transmitter laser operating at a specific channel wavelength, and the modulated outputs from the semiconductor lasers are combined onto a single fiber for transmission in their respective channels. The International Telecommunications Union (ITU) presently requires channel separations of approximately 0.4 nanometers, or about 50 GHz. This channel separation allows up to 128 channels to be carried by a single fiber within the bandwidth range of currently available fibers and fiber amplifiers. Improvements in fiber technology together with the ever-increasing demand for greater bandwidth will likely result in smaller channel separation in the future.

The drive towards greater bandwidth has led to use of precision wavelength-specific DWDM devices that require careful adjustment and calibration according to the narrow transmission channel spacings. Continuously tunable lasers have been developed to aid in the test and measurement of these sophisticated devices. Tunable lasers of this sort typically utilize a tuning element, such as a pivotally adjustable grating within an external cavity, in order to generate an adjustable wavelength sweep in the laser output that can be used in the characterization of precision WDM components.

One problem which can arise with such tunable lasers is "mode-hopping" wherein the laser changes frequency discontinuously to a different longitudinal mode. When used as a telecommunication transmitter, these mode hops will cause transmission errors in the modulated data stream. One approach taken for designing tunable lasers is to use a relatively long cavity with finely spaced modes, and tune the laser in a "quasi-continuous" manner,

When tuned, a DWDM transmitter must cease emission at the original wavelength of operation and then recommence emission at a second, precisely defined, wavelength. In general, emission at any other wavelength cannot be sent into the system since this may cause crosstalk between the channel being tuned and other transmission channels. One method for tuning is to mode hop the laser directly to the target wavelength. It is more practical to tune with the laser powered down, shuttered, filtered, or otherwise guaranteed to avoid other wavelengths during tuning, where these precautions may be taken at the system level or at the source. With these precautions, the precise mode hop behavior of the laser during tuning between channels is not important. It is important that the target wavelength is precisely achieved. The effective cavity length, which determines the exact wavelength of operation, must be precisely controlled. Only after tuning and transmission into the system commences must mode hopping, which causes amplitude and frequency changes in the source, be avoided.

In some DWDM systems, the channel frequencies are adjusted during operation to maximize system capacity at acceptable bit error rate. Telecommunication sources must operate over a large temperature range, with -5° C to 70° C being typical, and the effect this temperature has on effective cavity length, filter characteristics, and the general state of the laser, must be countered. The operation characteristics of thermal compensation and fine frequency control are similar and lead to the requirement that a telecommunication transmitter have precise control of cavity length and the wavelength filtering element. In view of these design considerations, a mode hop free tuning approach does not confer the same advantages in DWDM source applications as it does in a test and measurement application. There is a need for a tunable laser source for DWDM applications which has independent fine control of the wavelength filtering element and cavity length but is not restricted to avoiding mode hop behavior when coarsely tuning.

SUMMARY OF THE INVENTION

The invention provides an external cavity laser system and method wherein wavelength or channel selection is carried out independently from adjustment of external cavity optical path length. In general terms, the invention is an external cavity laser apparatus comprising a wavelength or channel selector tuner and an external cavity tuner

output facet along an optical path. An end mirror is located in the optical path, and the end mirror and second output facet define an external cavity for the laser. Output from the second output facet may be coupled into an optical fiber. A channel selector is positioned in the optical path between the second output facet and end mirror. The channel selector affects the passband of the intracavity filtering, and the channel selector is operatively coupled to the tuning mechanisms.

The channel selector may comprise an etalon with parallel reflective surfaces separated by a spacer layer. A tuning mechanism operates on the etalon by changing the optical path length of the spacer layer. For air or liquid spaced etalons, tuning mechanisms may comprise piezoelectric, thermal, pressure, and micromechanical mechanisms. For etalons filled with an electrooptic material such as Lithium Niobate or liquid crystals, the tuning mechanism may comprise an applied electric field. For solid etalons, the tuning mechanism may be thermal or mechanical. The channel selector may comprise a wedge etalon is tunable by macroscopic positional adjustment of the wedge etalon that changes the position at which the intracavity beam passes through the filter to a new position where the spacer layer is microscopically thicker or thinner and consequently the wavelength of peak transmission is longer or shorter respectively.

In other embodiments, the channel selector may comprise a surface grating that determines which wavelengths coming from the gain region are efficiently diffracted back into the gain region. The shape of the filter generally consists of a wavelength with maximum coupling efficiency surrounded by a passband of wavelengths with high coupling efficiency. The passband may be tuned in wavelength by adjusting the angle with which the beam strikes the grating. If the center of rotation is at the location where the beam center intersects the grating, then the passband will be adjusted with minimal change in the effective path length of the laser cavity. Translating the grating changes the effective path length of the laser cavity by an amount proportional to the component of translation along the beam path. The translation will have minimal effect on the passband provided that minimal rotation occurs with the translation.

The grating may be actuated by two mechanical actuators, such as micromechanical actuators or piezoelectric actuators, attached to two points on the grating. With this arrangement of actuators, each individual actuator will affect both the translation and

selector acts as a tunable intensity filter and coarsely determines wavelength by selecting which laser mode is lasing with high intensity. The uncoupling or orthogonalizing of the wavelength intensity filtering from the optical path length prevents wavelength changes which might otherwise occur due to vibration, thermal fluctuation, component wear and other factors affecting the channel selector.

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIG. 1 is a schematic diagram of an external cavity laser apparatus with a wedge etalon channel selector using independent wavelength tuning and external cavity tuning.

FIG. 2A-2C are graphical illustrations of passband characteristics of the external cavity laser of FIG. 1 for the wedge etalon, grid etalon and external cavity with respect to a selected channel in a wavelength grid.

FIG. 3A-3C are graphical illustrations of gain response to tuning of the external cavity laser of FIG. 1 for a plurality of channels in a wavelength grid.

FIG. 4 is a graphical illustration of a wavelength tuning profile of the external cavity laser apparatus of the invention shown with the wavelength grid defined by the grid generator.

FIG. 5 is an external cavity laser apparatus with a grating channel selector using independent wavelength tuning and external cavity tuning.

FIG. 6 is an external cavity laser apparatus with an electro-optic wavelength tuner and an electro-optic external cavity tuner.

DETAILED DESCRIPTION OF THE INVENTION

Referring more specifically to the drawings, for illustrative purposes the present invention is embodied in the apparatus and method shown in FIG. 1 through FIG. 6. It will be appreciated that the apparatus may vary as to configuration and as to details of the parts, and that the method may vary as to details and the order of events without departing from

The round trip amplitude strongly affects the relative intensity of the possible laser modes. The laser will generally operate on the mode with the highest round trip transmission, and if other modes have a round trip transmission less than half that of the lasing mode then the intensity of these other modes during normal operation will generally be less than a thousandth that of the lasing mode. This round trip amplitude filtering includes the spectral properties of all optical surfaces as well as gain in the gain region. Thus, for example, the transmission of wavelengths will be negligible outside the gain spectrum of the gain region even if an optical filter placed in the cavity has a transmission maximum at one of those wavelengths. This consideration is particularly relevant for etalon filters, which have multiple transmission peaks and gratings that have multiple diffraction orders. A static filter with a high transmission passband covering the tuning range of interest and low transmission outside the tuning range may be used to achieve a round trip amplitude filtering with no transmission maxima outside the tuning range of the laser. A grid generator filter with periodic transmission maxima will limit possible lasing to locations of substantial transmission near the maxima.

The round trip amplitude filtering also consists of a tunable filter with a single transmission peak within the tuning range of interest and a passband of high transmission surrounding the peak. Examples of such filters are etalons whose free spectral range exceeds the tuning range of interest, surface gratings, and Bragg or reflection gratings. The tunable filter may also consist of multiple elements which achieve a similar effect, for example an element with multiple transmission peaks and a tunable element with multiple peaks spaced differently from the first; the net effect of which is a single transmission peak that occurs where the peaks from both elements are made to overlap, and vernier style tuning of which peaks overlap.

Amplitude filtering may be considered as the total intracavity round trip amplitude transmission, and intensity filtering is the square of the amplitude filtering, i.e., the total intracavity round trip intensity transmission. Tunable amplitude filtering is provided to the total intracavity round trip amplitude transmission in the situation where this transmission may be effected by one or more tunable elements. The effect of a cavity path length change on the tunable amplitude filtering is minimal if the change in the center wavelength of the passband of the amplitude filter divided by the original wavelength is less than half the

Grid etalon 24 may be a parallel plate solid, liquid or gas spaced etalon, and may be tuned by precise dimensioning of the optical thickness between faces 28, 30 by thermal expansion and contraction via temperature control. The grid etalon 24 may alternatively be tuned by tilting to vary the optical thickness between faces 28, 30, by application of an electric field to an electro-optic etalon material, by changing the pressure of a gas spaced etalon, by inducing an index change in a nonlinear optical material with a second optical beam, or by changing the size of a spacer that determines the spacing in a gas or liquid filled etalon by thermal, piezoelectric, or micromechanical means. Grid etalon 24 alternatively may be actively tuned during laser operation as described in the U.S. Patent Application Ser. No. 09/900,474 entitled "External Cavity Laser with Continuous Tuning of Grid Generator" to inventor Andrew Daiber, co-filed herewith, and incorporated herein by reference.

The wedge etalon channel selector 26 acts as an interference filter with substantially parallel reflective surfaces 32 and 34. The separation between surfaces 32 and 34 may be finely changed along the laser axis, by an amount less then or equal to the wavelength of operation, by extending surfaces 32 and 34 beyond the area where the beam strikes these surfaces and tapering the spacer between these surfaces. The taper is small enough that the thickness change between 32 and 34 across the laser beam is negligible or tolerable, and is large enough that macroscopic motion of the filter across the beam introduces a microscopic change in the distance between 32 and 34 along the beam. The space between surfaces 32 and 34 may be gas filled, liquid filled, or filled with a solid. The space between surfaces 32 and 34 may be changed by thermally expanding a solid etalon, by thermally, piezoelectrically, or micromechanically expanding the spacing means in a gas or liquid etalon, by tilting the gas, solid, or liquid etalon, by changing the pressure of a gas spaced etalon, by using an electrooptic material as the spacer and changing the index with an applied electric field, by using a nonlinear optical material in the spacer layer and inducing a path length change with second optical beam, or by other tuning mechanism.

Wedge etalon 26 as shown in FIG. 1 is only one tunable element or channel selector that may be used in accordance with the invention in an external cavity laser, and various other types of channel selector may be used in place thereof, including grating, electrooptic, thin film and vernier tuning devices. The use of an air gap wedge etalon for channel selection is described in U.S. Patent No. 6,108,355, wherein the "wedge" is a tapered air gap

increasingly thinner portions of wedge etalon 26 and expose passbands to the optical path 22 that support correspondingly shorter wavelength channels. The free spectral range of wedge etalon 26 corresponds to the complete wavelength range of grid etalon 24 as noted above, so that a single loss minimum within the communications band can be tuned across the wavelength grid. The combined feedback to gain medium 12 from the grid etalon 24 and wedge etalon 26 support lasing at the center wavelength of a selected channel. Across the tuning range, the free spectral range of the wedge etalon 26 is broader than that of grid etalon 24.

Wedge etalon 26 is positionally tuned via a wavelength tuning assembly or mechanism which comprises a wavelength tuner drive element 36 structured and configured to adjustably position wedge etalon 26 according to selected channels. Wavelength tuner drive element 36 may comprise a stepper motor together with suitable hardware for precision translation of wedge etalon 26. Wavelength tuner drive 36 may alternatively comprise various types of actuators or adjustment mechanisms, including, but not limited to, DC servomotors, solenoids, voice coil actuators, piezoelectric actuators, ultrasonic drivers, shape memory devices, and like linear and/or rotation actuators. Where a different type of channel selector other than wedge etalon 26 is used with the invention, wavelength tuner drive 36 will accordingly be configured to tune the channel selector. A linear encoder 40 may be used in association with wedge etalon 26 and wavelength tuner drive 36 to ensure correct positioning of wedge etalon 26 by drive 36. A coarse spectrometer (not shown) that monitors the wavelength of operation may alternatively, or additionally, be used to ensure correct positioning of wedge etalon 26 by drive 36, or the correct positioning of a different type of channel selector by drive 36.

Wavelength tuner drive element 36 is operatively coupled to a wavelength controller 38, which provides signals to control the positioning of wedge etalon 26 by drive element 36. Wavelength controller 38 may include a data processor and memory (not shown) wherein are stored lookup tables of wavelength tuning information for wedge etalon 26, which provide positions correspond to selectable channel wavelengths. Wavelength controller 38 derives or creates appropriate channel or wavelength selection signals that are communicated to wavelength drive 36, which in turn drives or adjusts wedge etalon 26. Wavelength controller 38 may be internal to wavelength tuner drive 36, or may be external

and configured to positionally adjust gain medium 12 to tune the external cavity or to thermally adjust the optical path length of the gain medium 12 to tune the external cavity. In still other embodiments, external cavity drive 46 may be electro-optic in nature and carry out adjustment of optical path length l by changing the effective optical thickness of an electro-optic tuner (not shown) in the external cavity, as described further below. Electro-optic tuning of an external cavity is disclosed in U.S. Patent Application Ser. No. 09/900,426 entitled "Evaluation and Adjustment of Laser Losses According to Voltage Across Gain Medium" to inventors Daiber et al., the disclosure of which is incorporated herein by reference. Various mechanisms for tuning the optical path length l may be used with the invention, and the wavelength tuning will be configured accordingly to provide adjustment of optical path length l.

In certain embodiments, external cavity drive 46 may comprise a thermally tunable compensator element (not shown) that is configured to position end mirror 14 by heating or cooling the thermal compensator element according to optical cavity adjustment signals from external cavity controller 48 to a thermoelectric controller (also not shown) coupled to the thermally tunable compensator element. The use of a thermally controlled tuning element to positionally adjust an end mirror and other optical components in an external cavity laser is also described in U.S. Patent Application Ser. No. 09/814,646 to inventor Andrew Daiber, filed on March 21, 2001, and in U.S. Patent Application Ser. No. 09/900,443 entitled "Laser Apparatus with Active Thermal Tuning of External Cavity" to inventors Mark Rice et al., which is co-filed simultaneously herewith.

External cavity drive 46 is operatively coupled to an external cavity controller 48 which provides signals to control the positioning of end mirror 14 by external cavity drive 46. External cavity controller 46 may be operatively coupled to a voltage sensor 50, which in turn is operatively coupled to one of a pair of electrodes 52, 54 associated with gain medium 12. Electrodes 52, 54 provide a drive current to gain medium 12 from drive current source 56. Since optical feedback from end mirror 14 enters gain medium 12 through anti-reflection coated front facet 16, voltage across gain medium 12 as monitored by sensor 50 accurately indicates losses associated with the external cavity. External cavity controller 48 is configured to generate cavity mode signals from the output of voltage sensor 50, and to provide compensating signals to external cavity drive 46. The use of monitoring voltage

The finesse of grid etalon 24 and wedge etalon 26 determine the attenuation of neighboring modes or channels. As noted above, finesse is equal to the free spectral range over the full width half maximum, or finesse = FSR/FWHM. The width for a grid etalon passband 56 at half maximum is shown in FIG. 2B, and the width for a wedge etalon passband 58 at half maximum is shown in FIG. 2C. The positioning of grid etalon 24 and wedge etalon 26 within the external cavity improves side mode suppression.

The tuning of the passband PB3 of wedge etalon 26 between a channel centered at 1549.5 nm and an adjacent channel at 1550 nm is illustrated graphically in FIG. 3A-3C, wherein the selection of a channel generated by grid etalon 24 and the attenuation of adjacent channels or modes is shown. The external cavity passbands PB1 shown in FIG. 2A-2C are omitted from FIG. 3A-3C for clarity. The grid etalon 24 selects periodic longitudinal modes of the external cavity corresponding to the grid channel spacing while rejecting neighboring modes. The wedge etalon 26 selects a particular channel in the wavelength grid and rejects all other channels. The selected channel or lasing mode is stationary at one particular channel for filter offsets in the range of approximately plus or minus one half channel spacing. For larger channel offsets the lasing mode jumps to the next adjacent channel.

In FIG. 3A, the wedge etalon passband PB3 is centered with respect to the grid channel at 1549.5 nm. The relative gain associated with passband PB2 at 1549.5 nm is high, while the relative gain levels associated with adjacent passbands PB2 at 1549.0 nm and 1550.0 nm are suppressed relative to the selected 1549.5 nm channel. The gain associated with passbands PB2 at 1550.5 nm and 1548.5 nm is further suppressed. The dashed line indicates the relative gain for passbands PB2 without suppression by wedge etalon 26.

FIG. 3B shows the wedge etalon passband PB at a position in between the channels at 1549.5 nm and 1550.0 nm, as occurs during channel switching. The relative gain associated with passbands PB2 at 1549.5 nm and 1550.0 are both high, with neither channel suppressed. The relative gain levels associated with passbands PB2 at 1549.0 nm and 1550.5 nm are suppressed relative to the 1549.5 nm and 1550.0 nm channels. The dashed line indicates the relative gain for passbands PB2 without suppression by wedge etalon 26.

another peak of passband PB2 as shown in FIG 3C. In alternative embodiments of the present invention (not shown) where a grid generator PB2 is not present inside the laser cavity, tuning occurs similar to the tuning shown in FIG. 3A-3C except that the grid passbands PB2 are replaced by the laser mode passbands PB1.

The present invention utilizes wavelength tuning that is independent from or otherwise decoupled from the tuning of the external cavity optical path length in accordance with the invention. As a result, the external cavity laser 10 provides a "stair-step" or mode hop tuning profile. FIG. 4 graphically shows a "stair-step" laser output profile as relative channel selector position on the horizontal axis versus wavelength of lasing on the vertical axis. Channel selector passband peak wavelengths are shown as increments along the vertical axis, and corresponding channel selector positions for the passband peaks are shown as increments along the horizontal axis. On each "plateau" defined by the mode hop tuning, the wavelength of lasing remains stable despite changes in the peak transmission wavelength of the channel selector. The preferred embodiment is to lock the peak transmission wavelength of the channel selector to the wavelength of lasing to maximize the output power, maximize the side mode suppression ratio, and minimize the possibility that the channel selector position will deviate far enough to create a mode hop to a new channel. The lasing on each plateau P occurs in a longitudinal mode of the laser distinct from the longitudinal modes of all other plateaus P.

Referring now to FIG. 5, there is shown another embodiment external cavity laser apparatus 58 in accordance with the invention, wherein like reference numbers are used to denote like parts. As in the embodiment of FIG. 1, the relative sizes of and distances between components is exaggerated for clarity. The external cavity laser apparatus 58 is shown with a grating 60 as a wavelength tuner, and arranged in a Littrow configuration. Grating 60 is operatively coupled to actuators 62, 64 which are symmetrically located on grating 60 with respect to a point 66 on the surface of grating 60 which lies generally in the center of optical path 22. Actuators 62, 64 may be piezoelectric, micromechanical, or other type of actuator. A tuner 68 commands changes in the length of actuators 62, 64.

The external cavity laser 58 includes a wavelength selection control element 70 and an external cavity control element 72, which are operatively coupled to tuner 68. Tuner 68

are respectively positioned adjacent substrates 102, 104, and define reflective or partially reflective surfaces such that LC substrate acts as an etalon. Transparent electrodes 108, 110 may comprise, for example, an indium-tin oxide (ITO) conductor. Alignment layers (not shown), which may comprise oriented or grooved polymer layers, are positioned between LC material 86 and transparent electrodes 108, 110. The fabrication and use of liquid crystalline electro-optic devices of this sort is well known in the art.

First electro-optic tuning element 100 is operatively coupled to a wavelength controller 112 which provides an adjustable voltage to one of transparent electrodes 108, 110, the other of which is suitable grounded. LC material 106 comprises a plurality of individual, birefringent liquid crystalline molecules (not shown) that can undergo orientation in response to voltage applied across LC material 106 by electrodes 108, 110. Liquid crystalline materials of this sort are well known in the art and are not described herein. The change in orientation of the liquid crystalline molecules changes the refractive index of LC material 106, and hence the effective optical thickness of LC material 106. Thus, voltage applied across transparent electrodes 108, 110 by wavelength controller will vary the effective optical path length between partially reflective surfaces 108 and 110 experienced by a coherent beam as it passes through LC substrate 106 along optical path 22. The change in effective optical path length tunes the wavelength of maximum transmission of electro-optic tuning element 100. The use of an electro-optic channel selector is also disclosed in U.S. Patent Application Ser. No. 09/814,646 filed on March 21, 2001, the disclosure of which is incorporated herein by reference.

External cavity laser apparatus 98 also includes a second electro-optically activated tuning element 114 positioned in optical path 22 before end mirror 14 and after first electro-optic tuning element 100. Electro-optic tuning element 114 is operatively coupled to an external cavity controller 116, which in turn is operatively coupled to a photodetector 118 positioned in optical path 22 after end mirror 14. In this regard, end mirror 14 may be, for example, 95% reflective such that end mirror allows a portion of output from the external cavity laser 98 to reach photodetector 118. Photodetector 118 may alternatively be replaced by a voltage sensor configured to monitor voltage across gain medium 12 in the manner described above.

vary in magnitude and phase error according to alignment of an external cavity mode with the center wavelength of the passbands defined by electro-optic tuning element 100 and grid generator 24. In other words, the intensity variations and phase shift in the modulation signal provide an effective way to evaluate external cavity losses and develop corresponding error signals for the adjustment of external cavity optical path length. Thus, external cavity controller 116 derives error signals from the modulation introduced by the frequency dither, and communicates compensation signals to external cavity controller 116, which correspondingly adjusts the voltage applied across electro-optic substrate 120 to tune or adjust the optical path length *l* by changing the refractive index of substrate 120. The use of modulation elements to introduce frequency modulation or dither into laser components is described in U.S. Patent Application Ser. No. 09/900,426 entitled "Evaluation and Adjustment of Laser Losses According to Voltage Across Gain Medium" to inventors Daiber et al., noted above and incorporated herein by reference.

While the present invention has been described with reference to the specific embodiments thereof, it should be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the true spirit and scope of the invention. In addition, many modifications may be made to adapt a particular situation, material, composition of matter, process, process step or steps, to the objective, spirit and scope of the present invention. All such modifications are intended to be within the scope of the claims appended hereto.

configured to measure external cavity loss associated with cavity optical path length.

6. An external cavity laser, comprising:

(a) a wavelength tuning mechanism configured to select a transmission wavelength according to a wavelength selection signal; and

(b) an external cavity mode tuning mechanism configured to select a cavity optical path length according to a cavity mode signal;

(c) said wavelength tuning mechanism configured to operate independently from said cavity mode tuning mechanism.

7. The external cavity laser apparatus of claim 6, wherein said wavelength selection signal is derived independently from said cavity mode signal.

8. The external cavity laser apparatus of claim 7, wherein:

(a) said wavelength selection signal is acquired from wavelength selection data stored in a look-up table; and

(b) said cavity mode signal is derived from a detector configured to measure external cavity loss associated with cavity optical path length.

9. The external cavity laser apparatus of claim 6, wherein:

(a) said wavelength tuning mechanism is operatively coupled to a first controller and operable according to wavelength tuning data in a look-up table; and

(b) said external cavity tuning assembly is operatively coupled to a second controller and operable according to error signals derived from a detector configured to measure external cavity loss associated with cavity optical path length.

10. An external cavity laser apparatus, comprising:

(a) a wavelength tuning element; and

(b) an external cavity mode tuning element;

14. The external cavity laser apparatus of claim 13, wherein, said wavelength selection signal is derived from wavelength tuning data in a look-up table.

15. The external cavity laser apparatus of claim 13, wherein said cavity mode signal is an error signal derived from a detector configured to measure external cavity loss associated with cavity optical path length.

16. The external cavity laser apparatus of claim 15, wherein said detector comprises a voltage sensor configured measure voltage modulation across said gain medium.

17. The external cavity laser apparatus of claim 13, further comprising a modulation element, said modulation element operatively coupled to said external cavity and configured to introduce a modulation to said cavity optical path length, said modulation usable to derive said cavity error mode signal.

18. The external cavity laser apparatus of claim 13, wherein said cavity optical path length tuning assembly comprises a thermally tunable compensating member, said thermally tunable compensating member coupled to said end mirror.

19. The external cavity laser apparatus of claim 13, further comprising a grid generator positioned in said optical path.

20. A method for tuning an external cavity laser, comprising:

(a) tuning a channel selector with a first tuning element according to a first, wavelength selection signal; and

(b) tuning an external cavity optical path length with a second tuning element according to a second, cavity mode error signal;

(c) said tuning said channel selector carried out independently from said tuning said external cavity optical path length.

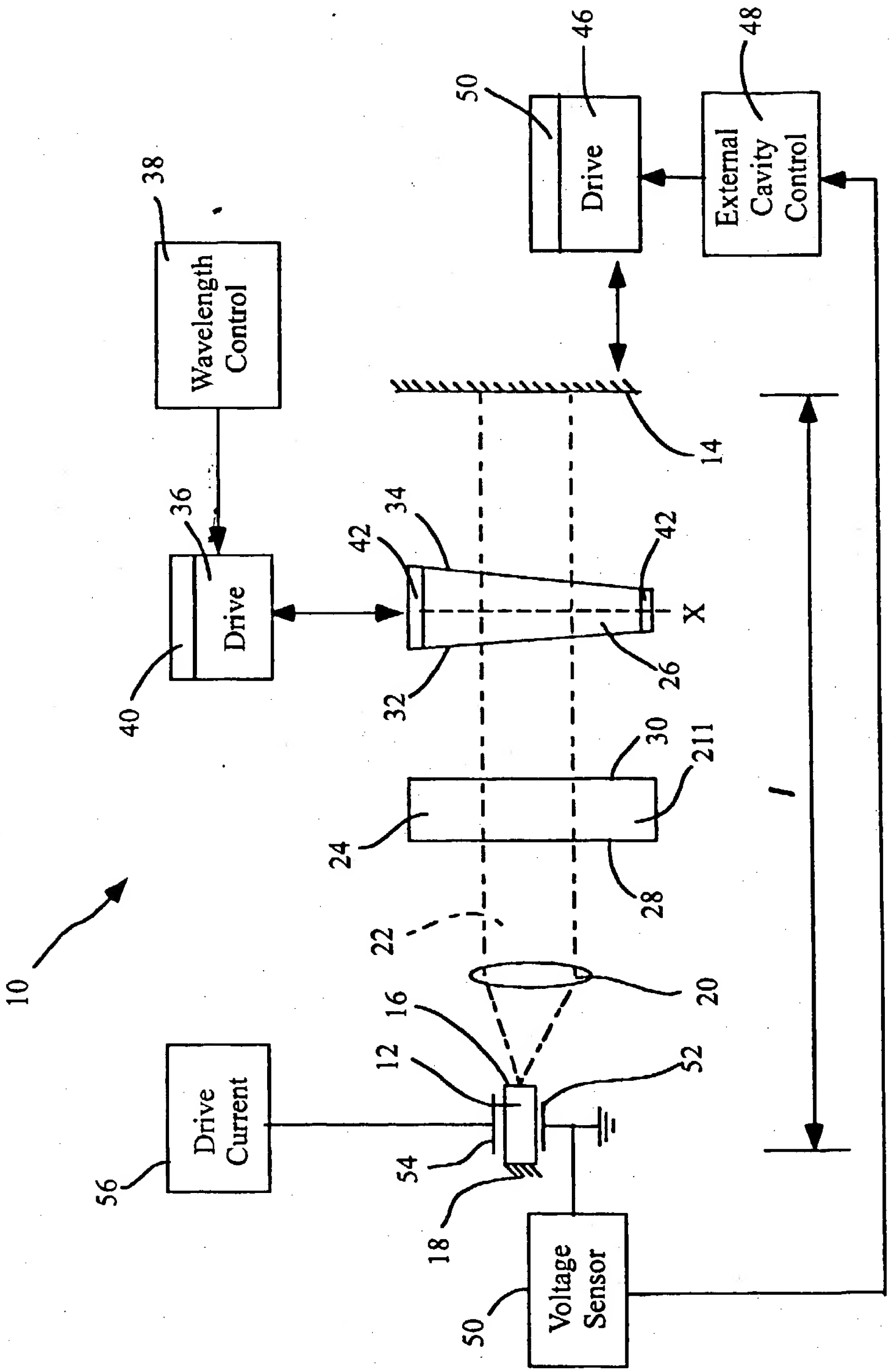
21. The method of claim 20, wherein said first, wavelength selection

(b) means for deriving an optical path length signal for said external cavity tuning means;

(c) said wavelength signal deriving means operable independently from said optical path length signal deriving means.

29. The laser apparatus of claim 27, wherein said wavelength tuning means comprises wavelength selection control means for actuating a channel selector according to signals derived from optical output of said laser.

30. The laser apparatus of claim 29, wherein said external cavity tuning means comprises external cavity control means for actuating a reflector according to signals derived from voltage monitored across a gain medium of said laser.


Wavelength Control
38
Drive
36
40
Drive
46
50
External Cavity Control
48
10
12
14
16
18
20
22
24
26
28
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32
34
42
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X
211
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Drive Current
56
54
52
Voltage Sensor
50

Fig.1

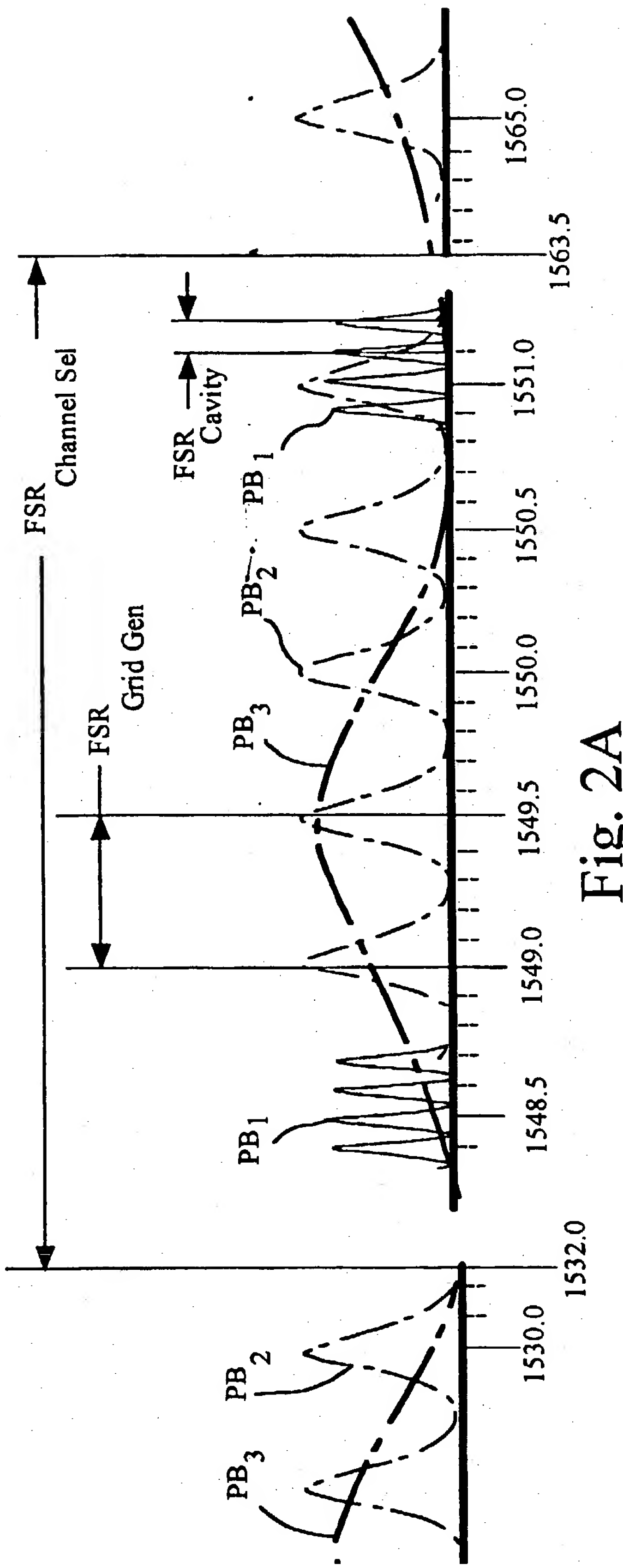


Fig. 2A

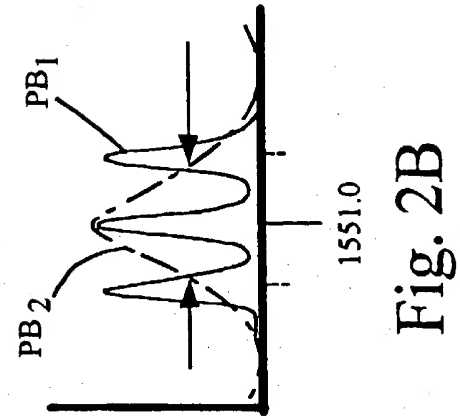


Fig. 2B

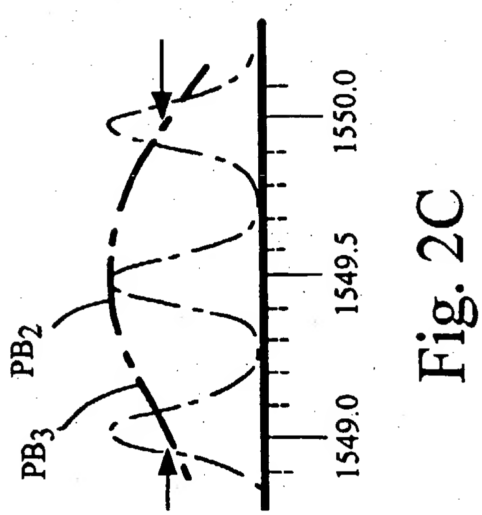


Fig. 2C

Fig. 3A

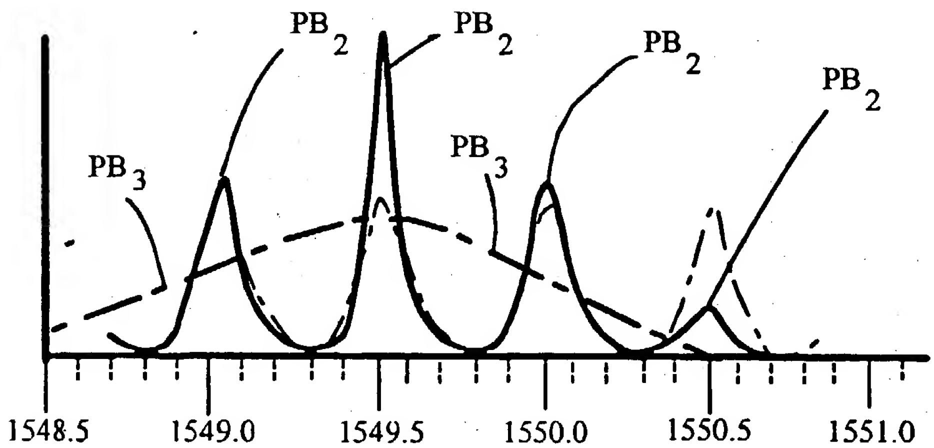


Fig. 3B

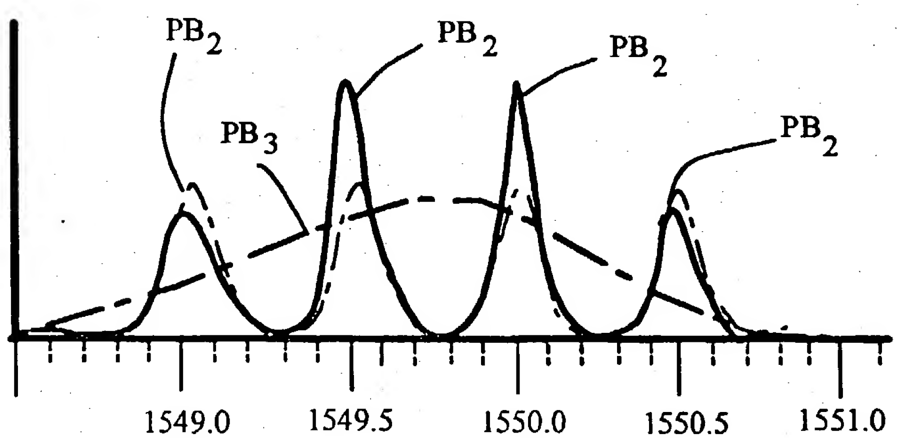
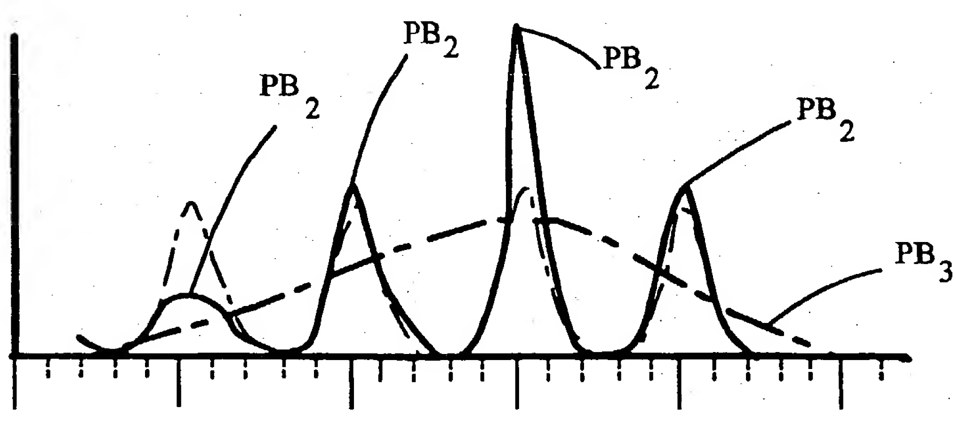


Fig. 3C



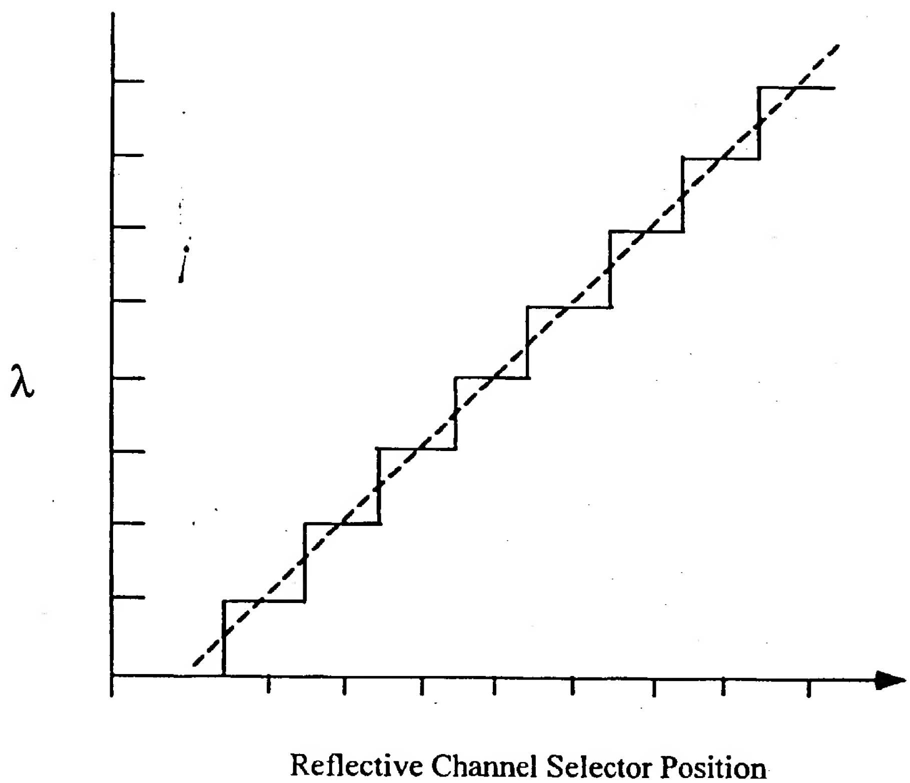


Fig. 4

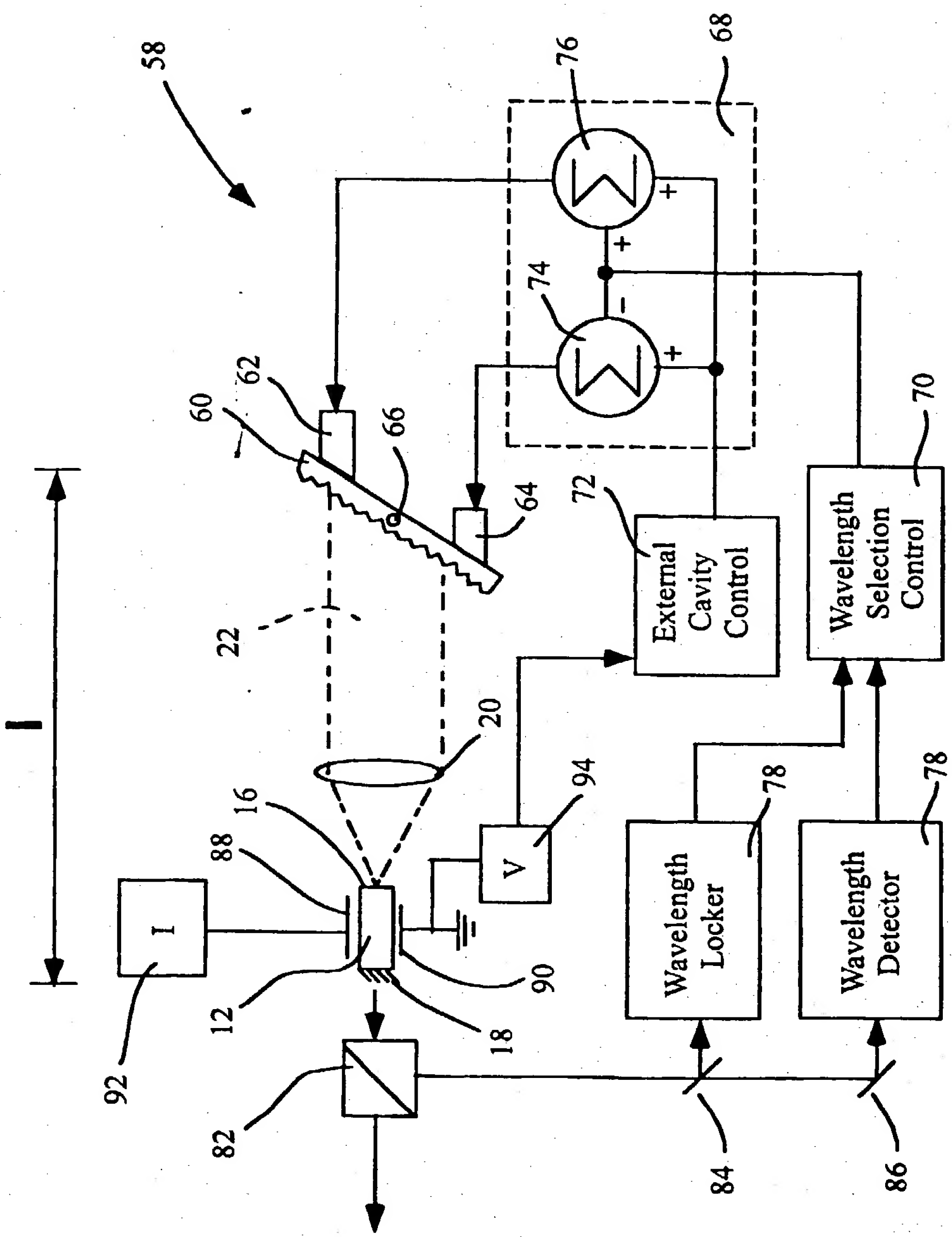
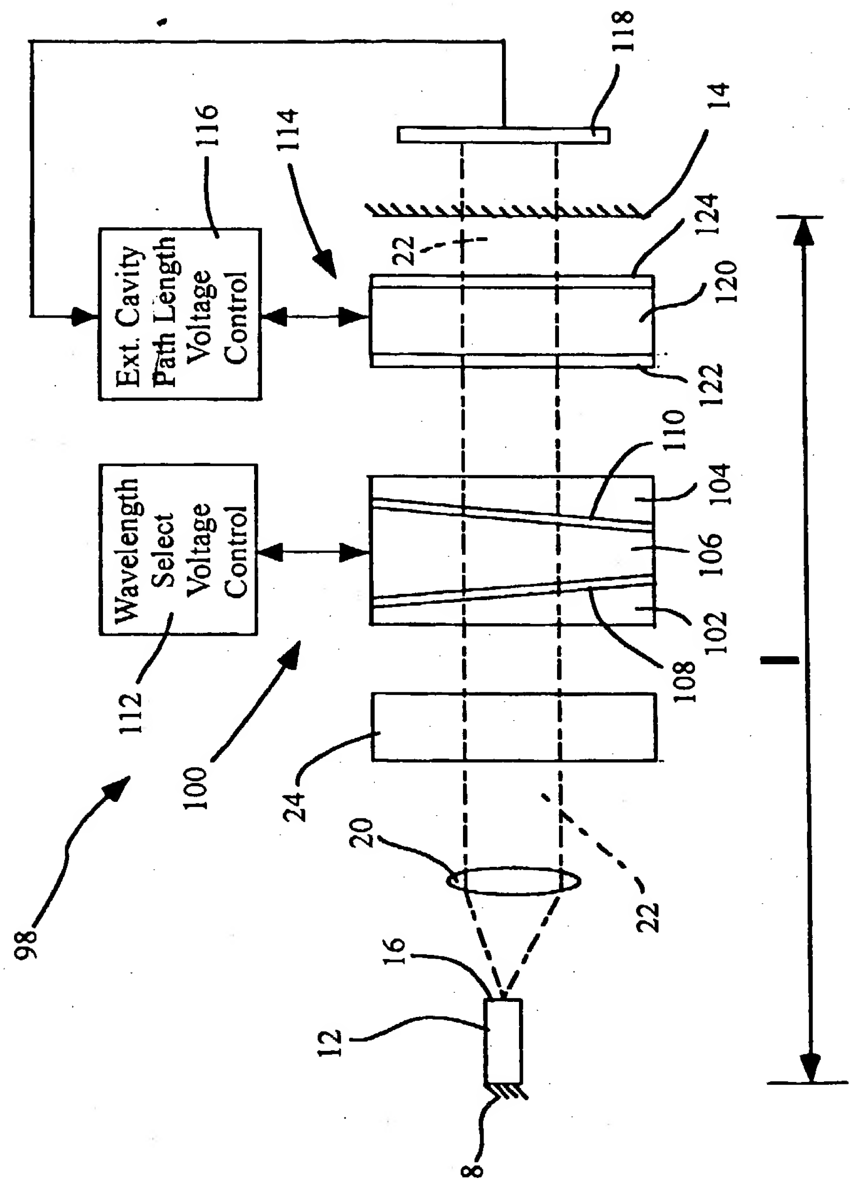

58
68
76
74
62
60
66
64
72
70
External Cavity Control
Wavelength Selection Control
22
20
16
88
94
V
I
12
90
18
92
82
Wavelength Locker
Wavelength Detector
78
78
84
86

Fig. 5


Ext. Cavity Path Length Voltage Control
Wavelength Select Voltage Control
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100
112
114
116
118
14
22
124
120
122
110
104
106
102
108
24
20
16
12
18
l

Fig. 6